www.czasopisma.pan.pl www.journals.pan.pl

Archives of Environmental Protection
Vol. 44 no. 4 pp. 38–49

PL ISSN 2083-4772
DOI 10.24425/aep.2018.122302

Optimum site selection for oil spill response center in the Marmara Sea using the AHP-TOPSIS method

Burak Koseoglu, Muge Buber*, Ali C. Toz

Dokuz Eylul University,Turkey
Maritime Faculty

*Corresponding author's e-mail: muge.buber@deu.edu.tr

Keywords: oil spill, MCDM, Marmara Sea, AHP-TOPSIS, Response Center.

Abstract: The aim of this study is to determine the optimum location for an oil spill response center in the Marmara Sea. The analytic hierarchy process (AHP) and technique for the order of preference by similarity to ideal solution (TOPSIS) method as the most preferred multi-criteria decision-making (MCDM) technique were used. The results reveal that the LOC criterion and PRA sub-criterion have the highest effects on the optimal location selection of the oil spill response center. According to the results, the most suitable location for the oil spill response center in the region is Izmit Bay Entrance. This location has been proposed for the response headquarters to manage the whole operation with the assistance of auxiliary installations in the area. In this study, only technical and operational variables are taken into account, but political and administrative criteria are excluded.

Introduction

Oil spill emergency planning is a complicated interdisciplinary activity that requires wide knowledge regarding the fate and trajectory of oil on water (Nordvik 1999).Emergency response planning is based on stochastic risk assessment methods that consider key elements such as oil type, meteorological factors, and quantity of oil (Wang et al. 2014). Accidental oil spills are usually unpredictable, and therefore efficient response operations, which are carried out against time, play an important role in reducing environmental impact (Toz et al. 2016).Arriving at the spill point immediately after the accident and deploying the response equipment timeously is vital for mitigation of the contamination effect (WWF 2007). The leading factors in oil spill response planning, such as location and infrastructure of the response center, identified at the strategic and tactical level (Obrien et al. 2017) are extremely important for the operational level effectiveness (Iakovou et al. 1997). The permanent storage of response equipment or its placement in a mobile unit offers various benefits to operators in terms of equipment deployment practices and the gaining of experience. However, placing response resources near risky areas also brings about certain challenges such as additional logistical needs and transportation costs (ITOPF 2002).

Oil spills are generally unpredictable disasters requiring immediate reaction in rapidly changing environments. The uncertainties in the environment force responders to make the best decisions to mitigate theadverse effects of disasters. Therefore,an effective risk assessment process is the most important step in the success of the operation. Optimization modeling in emergency response activities mainly focuses on the evaluation of multiple criteria (equipment stockpiles, reaction time, infrastructure, mobilization capability etc.) simultaneously. Therefore, multi-criteria decision-making (MCDM) techniques are generally utilized in solving such problems. MCDM methods are analytical methods that allow for the evaluation of many strategic and operational factors that can be measured with the involvement of a large number of people in the decision-making process (Dagdeviren et al. 2005). The MCDM technique mainly aims to assist decision-makers in selecting the 'best'possible alternative of those with different priority levels in a multi--criteria decision environment. The analytic hierarchy process (AHP) and technique for order of preference by similarity to ideal solution (TOPSIS) are the most preferred methods in decision--making in multi-criteria environments (Timor 2011).

Literature review

The number of optimization modeling studies regarding oil spill response planning has increased dramatically since the 1970s. Church and Revelle (1974) developed a partial covering method to locate equipment to respond to marine pollution incidents. Chames et al. (1979) used a "chance-constrained goal programming model" to optimize the capacity of the response infrastructure. Belardo et al. (1984) optimizedthe site selection for response equipment. Psaraftis et al. (1986) utilized a tactical model to determine locations for response equipment, considering the probability of oil spill occurrence and various spill scenarios. Iakovou et al. (1997) developed a linear integer programming method that makes decisions regarding the optimum locations for oil spill response centers and necessary equipment infrastructure. Srinivasa and Wilhelm (1997) used an integer programming model to determine the strategic response operations, which mainly aims to set optimum reaction times. Verma et al. (2013) developed a probabilistic formulation that optimizes the location and capacity of oil spill response centers. Ha (2018) performed a local pollution risk assessment based on accident probability and post-accident sensitivity using the AHP method in Korea.

The studies focusing on oil spill matters are mostly concentrated in the strategic regions including straits, narrow channels, gateways and inner seas. For this reason, the Marmara Sea and the Turkish straits have always been in the focus of those studies for years. Guvenet al. (1996) performed a study dealing with the effects of oil pollution from Nassia tanker in Istanbul Strait. Otay and Yenigun (2000) simulated the weathering processes of oil spill from Volganeft-248 in Istanbul Strait. Ors (2003) and Basar (2010) used simulation technique to predict weathering processes of oil in the Marmara Sea and Istanbul Strait. Dogan and Burak (2007) aimed to determine ecological hazard level in Turkish straits and Marmara Sea considering ship originated pollution. Alpar and Unlu (2007) performed environmental risk assessment through "chemical fingerprint approach" after the Volganeft-248 accident. Basar et al. (2006) utilized simulation technique to find risky areas for oil spillage after tanker accident at Istanbul Strait. Guven et al. (2007) aimed to determine pollution level of sediments of Turkish Straits and the Marmara Sea using sampling method between 2005 and 2007. Unlu (2007), in his study, characterized the chemical composition of the unknown oil spilled from the Haydarpasa Port through "advanced fingerprinting techniques and diagnostic ratio" method. Birpınar et al. (2009) tried to define environmental effects of maritime traffic on the Istanbul Strait through literature review. Bozkurtoglu (2017) used simulation technique to predict oil spill trajectory in the Istanbul Strait.

There are many scientific studies in the literature seeking solutions to the facility location problem with multi-criteria decision-making approach models. Yap et al. (2017) and Hong and Xiaohua (2011) utilized the AHP method to set the optimum location of emergency logistics centers. In the solutions of multi-criteria decision-making problems, AHP and TOPSIS have been used in many studies integrally. The literature shows that the AHP-TOPSIS method is preferred, especially in terms of solutionsto landfill site selection problems (Beskese et al. 2015, Soltanalizadeh et al. 2014, Ertugruland Karakasoglu 2008, Hanine et al. 2016, Yari et al. 2013, Kharat et al. 2016, Hanine et al. 2017). In addition, Gumusay et al. (2016) and Coskun (2016) carried out research aimedatdeterminingthe best location for construction sites of residential areas and marinas.In summary, although there have been many studies in the literature regarding location selection in emergencies, the issue of optimum location of oil spill response centers is a matter of concern.

Materials and methods

The aim of this study is to determine the optimum location for an oil spill response center in the Marmara Sea usingthe AHP-TOPSIS method. For this purpose, the relevant literature isfirst reviewed,andthen expert opinions are obtained. The weight of each parameter is calculated using the AHP method. Then, the TOPSIS method is used with the consideration of each alternative's ranking. Finally, a hypothetical study is performed through a case study to find the optimum location for an oil spill response center in the Marmara Sea. The evaluation process of the study is shown in Fig. 1.

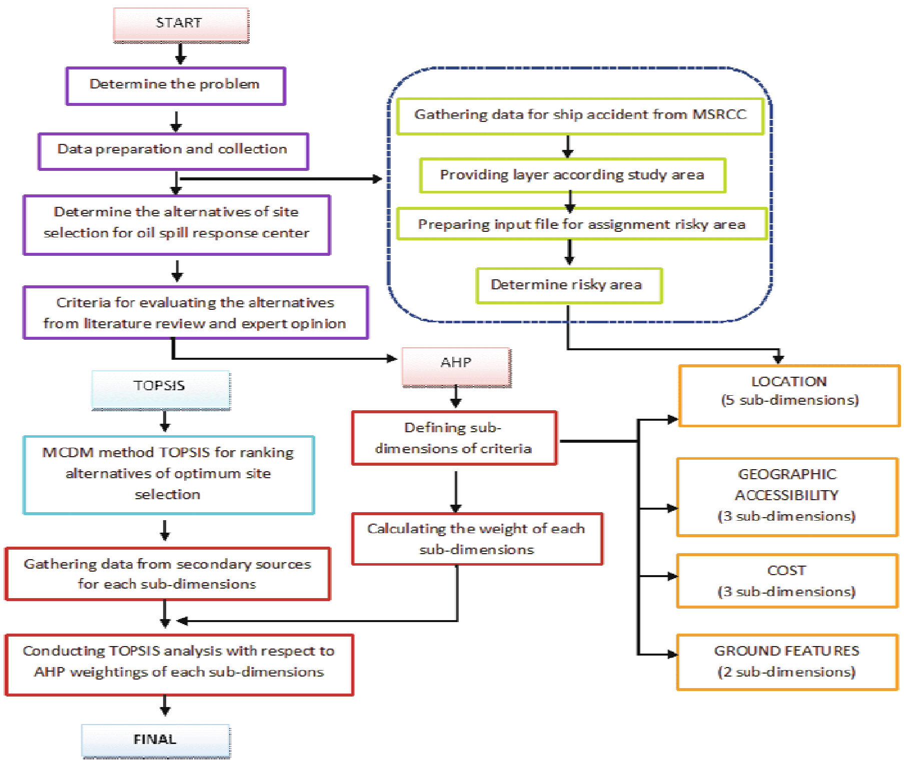

Fig. 1. Proposed model of the study
Source: Created by authors.

As understood from the figure, initially, the decision-making problem and study site are identified. After determining the study site, alternative locations for oil spill response centersare identified. Then, the evaluation criteria of the response locations are obtained from the literature review and expert opinions. The AHP method is performed with the data provided and the weight ratios are calculated. Finally, TOPSIS is carried out to calculate the ranking of each alternative.

AHP algorithm

The purpose of the AHP method is to ensure that the decision--making process is completed in the most efficient manner, taking into account the individual judgments of the decision--makers and the comparison consistency of the choices in this process, by placing the associated priorities for a given set of options on a scale. This approach supports judgments based on the decision-maker's knowledge and experience. The AHP provides a simple and effective solution in a multi criteria environment, taking into account all the factors and the systematic way of organizing the countable and uncountable factors (Saaty and Vargas 1982).The steps ofthe AHP method are explained as follows (Saaty 1980);

Step 1: In the first stage, the hierarchy explaining the main research problem is established. The hierarchy should include the main goal at the top and alternatives at the bottom. It is important that the number of criteria that impact the endpoint be correctly determined and that detailed descriptions of each criterion are made, so that pairwise comparisons can be made consistently and logically. The standard hierarchic structure of AHP is shown in Fig. 2.

Step 2: After the hierarchical model is established, the pairwise comparison decision matrices are constructed to evaluate alternatives on the basis of each factor and determine the importance levels of the factors themselves.

$$X = \begin{bmatrix} x_{11} & \Lambda & x_{12} & \Lambda & x_{1n} \\ M & & M & & M \\ x_{i1} & \Lambda & x_{i2} & \Lambda & x_{i3} \\ M & & M & & M \\ x_{n1} & \Lambda & x_{n2} & \Lambda & x_{nn} \end{bmatrix} \tag{1}$$

The importance scale of 1–9 (Table1) used by Saaty (1980) is used to construct these matrices.

Step 3: After generating the pairwise comparison matrices, the next step is to calculate the priority or weight vectors. According to the AHP methodology, the eigenvalues and eigenvectors of the comparison matrix help to determine the priority order. The eigenvector corresponding to the largest eigenvalue determines the priorities (Dagdeviren 2002).

According to the Saaty theory, it is possible to prove that each matrix has the following properties:

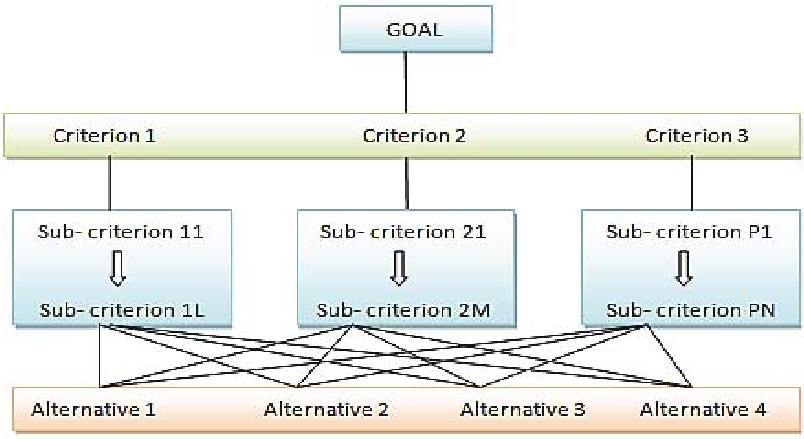

Fig. 2. Generic hierarchic structure
Source: Saaty 1980.

Table. 1. Explanation of AHP's Gradation Scale

Option	Numerical Value(s)
Equal	1
Marginally Strong	3
Strong	5
Very Strong	7
Extremely Strong	9
Intermediate Values to Reflect Fuzzy Inputs	2, 4, 6, 8
Reflecting Dominance of Second Alternative Compared with the First	Reciprocals

Source: Saaty 1980.

$$W = \begin{matrix} & w_1 & \Lambda & w_j & \Lambda & w_n \\ w_1 & w_1/w_1 & \Lambda & w_1/w_j & \Lambda & w_1/w_n \\ M & M & & M & & M \\ w_i & w_i/w_1 & \Lambda & w_i/w_j & \Lambda & w_i/w_n \\ M & M & & M & & M \\ w_n & w_n/w_1 & \Lambda & w_n/w_j & \Lambda & w_n/w_n \end{matrix} \quad (2)$$

Where "n" is the number of sub-criteria included in this hierarchical model.

W and w are multiplied;

$$W.w = \begin{matrix} & w_1 & \Lambda & w_j & \Lambda & w_n \\ w_1 & w_1/w_1 & \Lambda & w_1/w_j & \Lambda & w_1/w_n \\ M & M & & M & & M \\ w_i & w_i/w_1 & \Lambda & w_i/w_j & \Lambda & w_i/w_n \\ M & M & & M & & M \\ w_n & w_n/w_1 & \Lambda & w_n/w_j & \Lambda & w_n/w_n \end{matrix} . \begin{bmatrix} w_1 \\ M \\ w_i \\ M \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ M \\ w_i \\ M \\ w_n \end{bmatrix} \quad (3)$$

$$(W - nI)w = 0 \quad (4)$$

The solution of the above equation is the problem of finding the eigenvalue. $Hw = \lambda_{max} w$ is calculated by the w eigenvector based on λ_{max} which provides the equation. λ_{max} is the largest eigenvalue of the matrix X and w is obtained by the equation $(X - \lambda_{max} I)\mathbf{w} = 0$ depending on the eigenvector λ_{max}.

Step 4: The consistency ratio (C.R.) is calculated in the AHP to determine whether the decision-maker is consistent when making comparisons. In this calculation, the random index (R.I.) numbers developed by Saaty (1980) at the Wharton School of Business are used depending on the number of alternatives. The consistency index (CI) is calculated as

$$CI = (\lambda_{max} - \mathrm{n})/(n - 1) \quad (5)$$

whereis λ_{max} the maximum eigenvalue of the matrix. The ratio calculated is defined as CR. If the calculated value is less than 0.10, then the generated comparison matrix is consistent. Otherwise, the comparison matrix is inconsistent and needs to be rearranged (Saaty 1980).

$$CR = CI/RI \quad (6)$$

Step 5: The final step of the AHP is to multiply the importance weights of the factors with the weights of the alternatives and the priority value of each alternate. The alternative with the greatest priority based on this calculation is determined as the best alternative for the decision problem.

TOPSIS algorithm

The TOPSIS method wasintroduced by Chen and Hwang (1992) with reference to the work of Hwangand Yoon (1981). The multi-criteria decision problem with n alternatives and m criteria can be represented by n points in m-dimensional space. Hwang and Yoon (1981) constructed the TOPSIS method based on the assumption that the solution alternatives are the shortest distance to the positive ideal solution point and the farthest distance to the negative ideal solution point (Olson 2004). The steps of the TOPSIS method can be expressed as follows (Hwang and Yoon 1981);

Step 1: This step is mainly based on the construction of the decision matrix of each criterion based on the data representing the problem. If the number of alternatives is "m" and the number of criteria is "n", then the decision matrix having an order of "m×n" is represented as follows:

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \Lambda & x_{1n} \\ x_{21} & x_{22} & \Lambda & x_{2n} \\ M & M & M & M \\ M & M & M & M \\ M & M & M & M \\ x_{m1} & x_{m2} & x_{m3} & x_{mn} \end{bmatrix} \quad (7)$$

where an element X_{ij} of the decision matrix, represents the actual value of the i_{th} alternative in terms of j_{th} decision criteria.

Step 2: The square root of the sum of the squares of the points or features belonging to the criteria in the decision matrix is determined and the matrix is normalized. The normalized value r_{ij} is calculated as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad i = 1, 2, ..., \mathrm{m \ and} \ j = 1, 2, ..., \mathrm{n}. \quad (8)$$

Step 3: The elements of the normalized decision matrix are weighted according to the importance given to the criteria. Here, the subjective opinions of the decision-maker are included in determining the weights. The weighted normalized value is calculated asfollows:

$$v_{ij} = rij \times w_j \qquad i = 1, 2, ..., \mathrm{m \ and} \ j = 1, 2, ..., \mathrm{n}. \quad (9)$$

where v_{ij} is the weight of the j^{th} criterion or attribute and $\sum_{j=1}^{n} w_j = 1$.

Step 4: The ideal (A^*) and negative ideal (A^-) points are defined. Here, the weighted matrix (D) determines the maximum and minimum values in each column.

$$A^* = \left\{ \left(\max_i v_{ij} \,|j \in C_b| \right), \left(\min_i v_{ij} \,|j \in C_c| \right) \right\} = \{ v_j^* | j = 1,2, \dots, m| \} \quad (10)$$

$$A^- = \left\{ \left(\min_i v_{ij} \,|j \in C_b| \right), \left(\max_i v_{ij} \,|j \in C_c| \right) \right\} = \{ v_j^- | j = 1,2, \dots, m| \} \quad (11)$$

Step 5: After defining the ideal points, the Euclidean distance to the maximum and minimum ideal point is calculated using the following formula:

$$S_i^* = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^* \right)^2}, j = 1,2, \dots, m \quad (12)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^- \right)^2}, j = 1,2, \dots, m \quad (13)$$

Step 6: The relative order and score of each alternative is calculated according to the following formula. The relative closeness of the alternative A_i with respect to A^* is defined as follows:

$$RC_i^* = \frac{S_i^-}{S_i^* + S_i^-}, i = 1, 2, \ldots, \mathrm{m} \tag{14}$$

According to this formula, as the distance value increases from the negative ideal solution, the ideal solution approximation value increases.

Step 7: The ranking of each alternative is calculated considering the relative proximity value created for each alternative. Accordingly, the alternative of the shortest distance to the ideal solution is accepted as the best alternative.

Study area

In this study, the Marmara Sea, with its high domestic and international shipping traffic capacity, consisting of transit and direct passages,is selected as the study site (Bolat 2010). The Marmara Sea, an inner sea with a 164 nautical mile waterline for ship passage, isthe region that separates the Black Sea and Aegean Sea. The area is connected to the Black Sea through the Istanbul Strait to the north, and to Aegean Sea through the Strait of Canakkaleto the south (Akten 2004). The geographical limits of the Marmara Sea are shown in Fig. 3.

The area has witnessed a rapid increase in ship traffic due to increased trade volume in recent years. In 2017, a total of 87,593 ships (42,978 ships from the Istanbul Strait and 44,615 from the Canakkale Strait) sailed through the straits (Usluer and Alkan 2016). The number of ships, especially tankers passing through the Turkish Straits, increased in direct proportion to the growth of trade volume in the region, making it inevitable to take measures related to maritime traffic. The ship traffic is concentrated in certain regions in the Marmara Sea. The area has special importance in terms of safety of navigation, depending on the risks from geographical constraints and increasing ship traffic as shown in Fig. 4.

As it is understood from the figure, the study area is one of the busiest transit regions of the world in terms of ship traffic. In parallel with the increase in offshore oil trade, there has been a substantial increase in the number of tankers navigating the region in recent years. Most of these vessels navigating through the Black Sea do not meet the requirements of international standards. This region has strategic importance not only for transit ships, but also for vessels visiting the terminals located in the Marmara Sea. Tupras, where approximately 11 million tons of oil is handled annually, is located in the Bay of Izmit. There are also many terminals handling dangerous cargo in this area, as shown in Fig. 5.

The figure shows that liquid cargo handling facilities operating in the Marmara Sea are concentrated in the vicinity of Tekirdağ, Istanbul, and Izmit. These regions are considered extremely risky in terms of sea accidents, which may havecatastrophic consequences (Essiz and Dagkıran 2017). In this study, ship accidents have been taken into consideration as the main source of pollution. The regions bearing the risk of pollution are determined by putting accident data into the map. To identify the risky areas in the region, a list of the accidents, which was obtained from the MRCC (Mission Rescue and Coordination Center) database,was compiledand transferred to a Microsoft Excel sheet with the adaption of the file format of the Map Info 8.0 software. Fig. 6 shows the geographical distributions of ship accidents in the Marmara Sea between 2006 and 2017.

Between 2006 and 2017, a total of 637 marine accidents occurred in the Marmara Sea–128 in the Dardanelles, 440 in the Istanbul Strait, and 69 in other regions. It is clearly seen from the figure that the ship accidents are concentrated in regions where traffic intensity is high and geographical constraints are present. The fact that tanker-type vessels are involved in the accidents also increases the risk of marine pollution in the region.

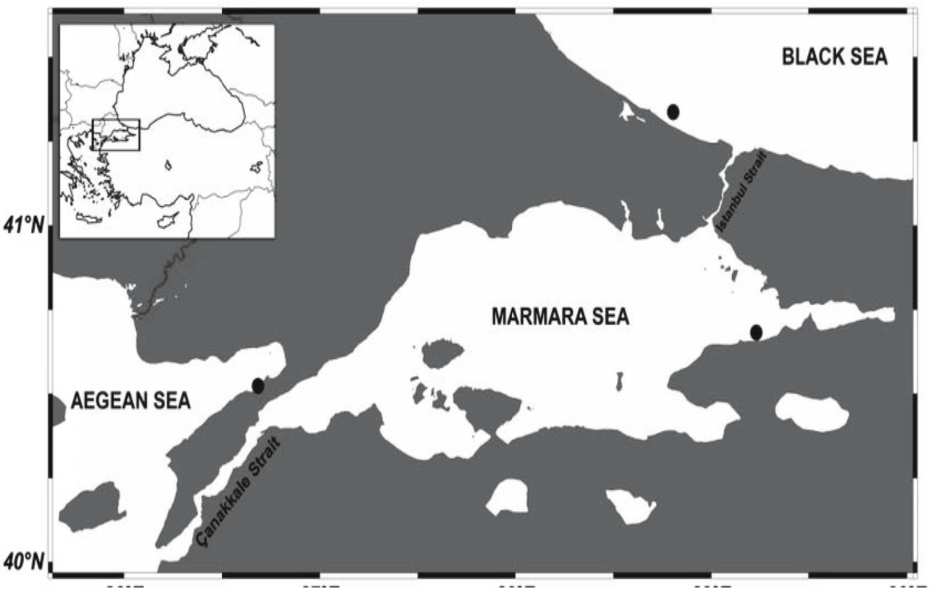

Fig. 3. Geographical limits of the Marmara Sea
Source: Tugrul et al. 2002.

The area's exposure risk level of natural disaster is the other factor considered by decision-makers regarding the optimum location for the oil spill response center. Earthquakes are the most likely natural disaster that may have devastating effects in the region. The map of this risk in the region is shown in Fig. 7.

As seen in the figure, this region is on the fault lines with varying earthquake risks levels. Besides, two of the proposed alternative locations are in the most risky zone where earthquakes frequently were experienced. The most active fault line in the region passes under the Marmara Sea and often causes earthquakes of varying degrees of severity. The most powerful earthquake (Magnitude of 7.4) struck Izmit region in 1999 and 17,000 people were killed. Therefore, in this area, additional measures must be taken to increase resilience to natural disasters while building new structures.

Determining and weighing the criteria

In this study, the criteria determining the optimum site selection for an oil spill response center in the Marmara Sea have beenobtained from the review of relevant literature and expert

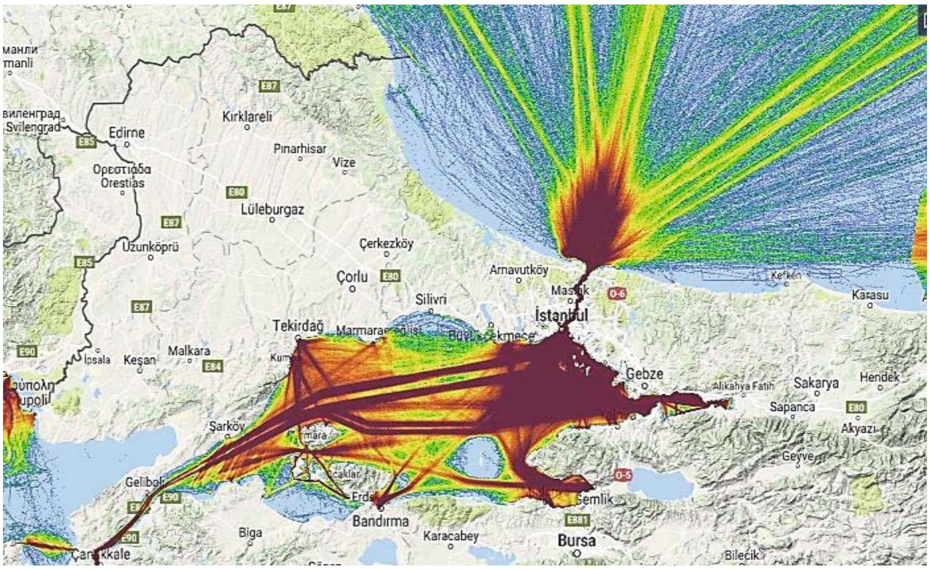

Fig. 4. Marmara Sea shipping traffic density map (2017)
Source: IHS, 2017

Note. The color coding represents traffic density in each area. The numbers refer to the daily quantities of distinct vessels and their positions are counted per square km. The colors represent: blue–less than 30; green–30 to 70; yellow–71 to 140; red–more than 140. This coding was created using the AIS data of the vessels passing through the area.

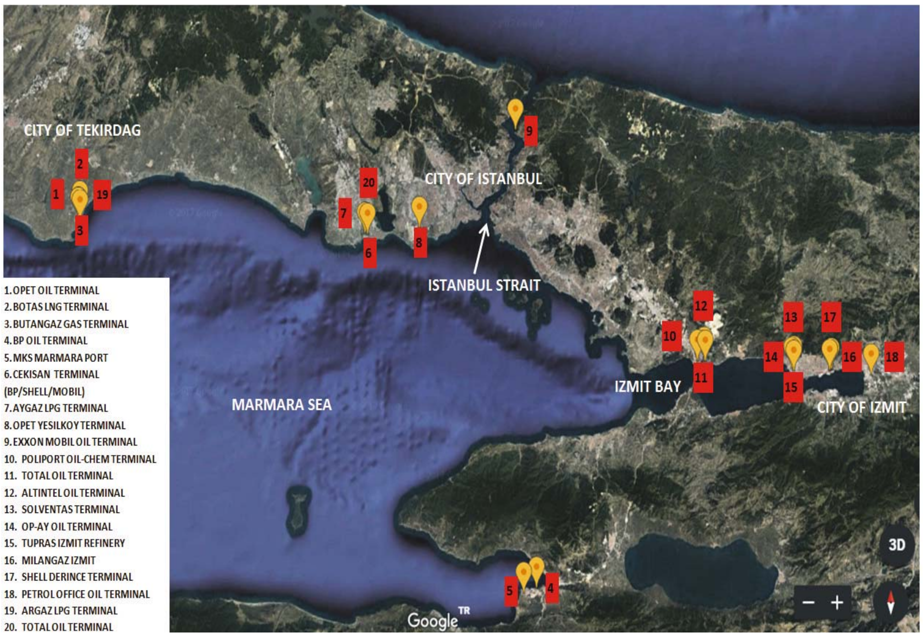

Fig. 5. Locations of liquid cargo handling facilities in the Marmara Sea
Source: Created by authors using data provided by BOSMAR 2017.

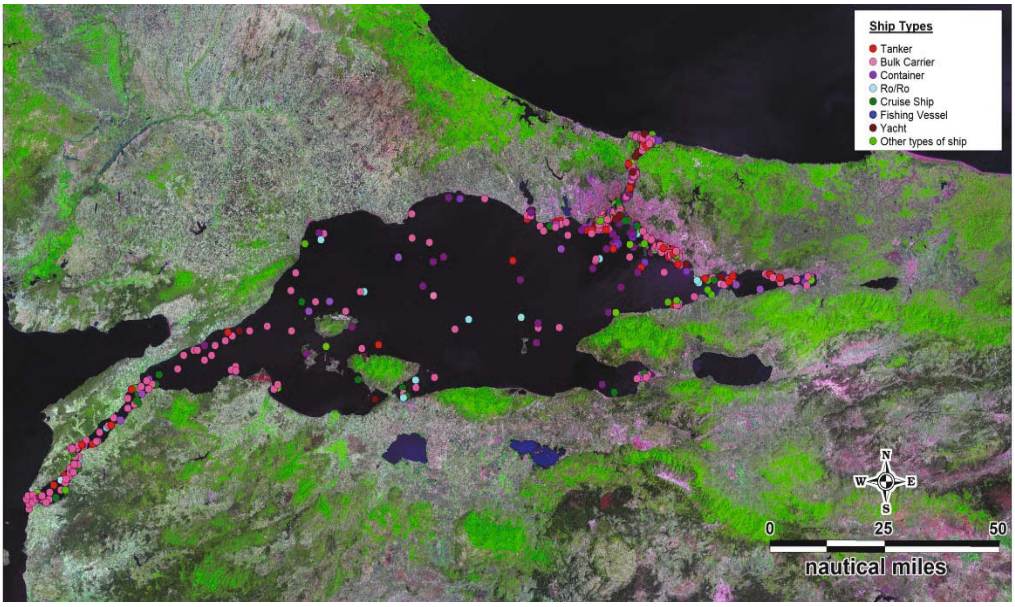

Fig. 6. Geographical distributions of ship accidents according to ship type in the Marmara Sea (2006–2017)
Source: Created by authors using data provided by TMRCC 2017.

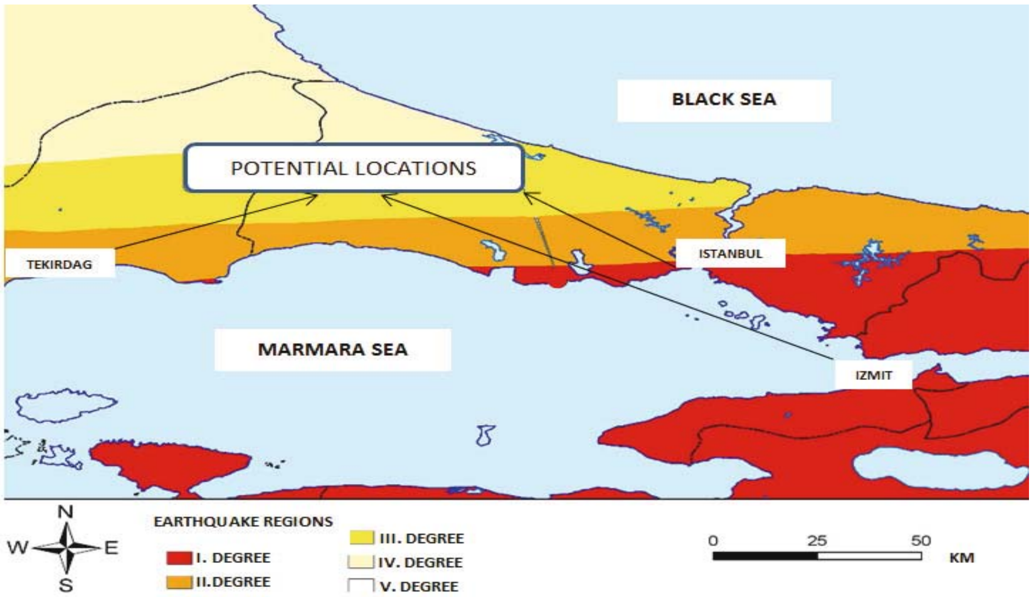

Fig. 7. Natural disaster risklevel of study area
Source: Aktar et al. 2017.

Note: 1st Degree Zones(Ground Acceleration (GA)>0.4g), 2nd Degree Zones (0.3g<GA<0.4g), 3rd Degree Zones (0.2g<GA<0.3g), 4th Degree Zones (0.1g<GA<0.2g), 5th Degree Zones (0.1g>GA). Acceleration: 981 cm/s^2.

opinions. Following the literature review, expert opinions are used in determining and then weighing the criteria. The experts are selected from people who work at different levels of relevant sectorsand have considerable experience in their respective fields. The details of the experts participating in this study are given in Table 2.

A hierarchical structure (Fig. 8) isestablished to estimate the weightings for each item. A survey isconducted using eight experts in marine pollution clean-up, who work for universities, governmental bodies and research institutions. The weightings per stage are calculated from the lowest stratum, based on pairwise comparison.

The process of AHP site selection starts with the identification of the relevant field selection factors. These factors are then structured hierarchically towards the various criteria and sub-criteria at successive levels of a general goal. As shown in the figure, 14 sub-criteria under thefour main criteria that determine the optimum site selection for the oil spill response center,are defined. The items in the criteriaarecategorized into accident probability factors. The

Table 2. Details of the Experts

Expert	Company	Department	Position	Experience (Years)
1	Republic of Turkey Ministry of Environment and Urbanization	Directorate General of Spatial Planning	Branch Manager	17
2	Republic of Turkey Ministry of Environment and Urbanization	Directorate General of Spatial Planning	City Planner	13
3	Republic of Turkey Ministry of Environment and Urbanization	Directorate General of Geographic Information Systems	Head of Department	16
4	DokuzEylul University Maritime Faculty	Marine Transportation Engineering	Academician/OPRC–HNS Trainer	15
5	BOWMAR Shipping & Logistic Ltd.	Technical Department	Master Mariner/Hazard Mitigation Expert/	30
6	Republic of Turkey Ministry of Transport, Maritime Affairs and Communications	Izmir Port Authority	Marine Expert/Master Mariner	17
7	MEKE Marine Environmental Protection Services Ltd.	CEO	President OPRC-HNS Trainer	30
8	SEAGULL Environment Cleaning and Oil Spill Response Ltd.	CEO	President OPRC-HNS Trainer	18

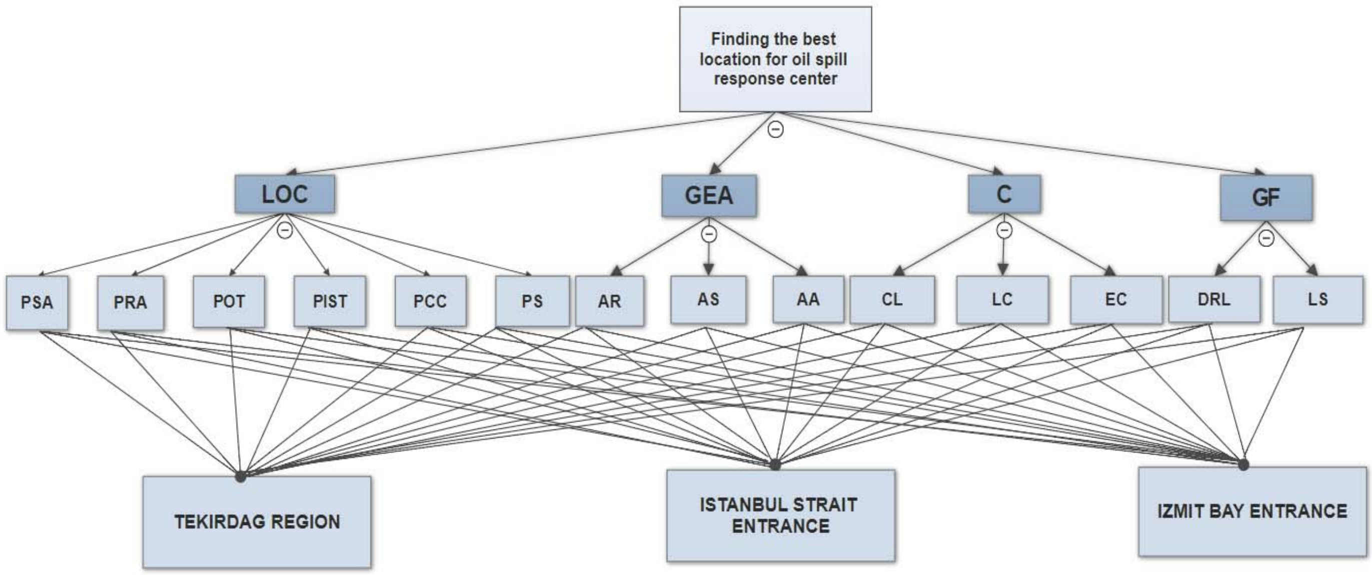

Fig. 8. Hierarchical Structure of AHP

LOC: Location
PSA: Proximity to Naturally Sensitive Areas
PRA: Proximity to Risky Areas
POT: Proximity to Oil Terminals
PIST: Proximity to Areas with Intensive Ship Traffic
PCC: Proximity to City Center
PS: Proximity to the Seaside

GF: Ground Features
DRL: Disaster Resiliency Level
LS: Land Size

GEA: Geographic Accessibility
AR: Accessibility by Road
AS: Accessibility by Sea
AA: Accessibility by Air

C: Cost
EC: Equipment Cost
LC: Labour Cost
CL: Cost of Land

former includes the volume of oil transport, distribution of industrial facilities (oil storage facilities), entry and departure of ships, and previous oil spill accidents;the latter includes aquaculture distribution, seas of high environmental significance, and amenities.

Potential locations for the oil spill response center

In the light of the opinions of sector experts, three alternative sites which could serve as emergency response centers in this regionare identified, as shown in Fig. 9.

As shown in the figure, the potential sites are on routes with heavy ship traffic. Moreover, the potential sites are located in close proximity to sensitive areas where immediate action is required in the case of an oil spill.

Findings

AHP results

An AHP questionnaire wasapplied to the experts to compare the importance level of each criterion identified in the hierarchical structural model. Consistency ratios (CR) arecalculated separately for each response. The rating scale proposed by Saaty (1980) is used to measure the weights of each item in a pairwise comparison. A normalization matrix is structured by taking the average values of the rows to determine the priority level of each criterion. The findings are summarized as follows:

Table 3 indicates that the LOC criterion is the most important factor in optimum site selection decision, with a weight of 0.497. Other criteria are listed as follows according to their importance level: GEA (0.367), C (0.072), and finally GF (0.064). The CRis calculated as 0.024, which is less than 0.1,and shows that the judgments for each criterion are consistent.

According to the results presented in Table 4, the PRA sub criterion has the highest weight value (0.331) and PCC has the lowest weight value (0.041). Because the CR value (0.05) is smaller than the critical value (0.1), this calculation, which

Fig. 9. Potential sites of oil spill response centres
Source: Created by authors

Table 3. Weights, pairwise comparisons, and consistency values of the main criteria

λ_{max}: 4.065 **RI:** 0.90 **CI:** 0.022 **CR:** 0.024						
		LOC	GEA	C	GF	**WEIGHT**
MAIN CRIERIA	LOC	1.000	1.594	8.275	5.833	**0.497**
	GEA	0.627	1.000	6.046	6.046	**0.367**
	C	0.121	0.165	1.000	1.505	**0.072**
	GF	0.171	0.165	0.664	1.000	**0.064**

Table 4. Weights, pairwise comparisons, and consistency values of location sub-criteria

λ_{max}: 6.320 **RI:** 1.24 **CI:** 0.064 **CR:** 0.05							
	PSA	**PRA**	**POT**	**PIST**	**PS**	**PCC**	**WEIGHT**
PSA	1.000	0.716	0.901	0.946	1.382	4.757	0.172
PRA	1.398	1.000	3.349	2.536	3.349	4.584	0.331
POT	1.110	0.299	1.000	2.447	2.015	4.810	0.198
PIST	1.057	0.394	0.409	1.000	1.870	3.222	0.141
PS	0.724	0.299	0.496	0.535	1.000	4.985	0.116
PCC	0.210	0.218	0.208	0.310	0.201	1.000	0.041

compares the importance levels of the LOC sub-dimensions, is considered to be consistent.

The calculations of the GEA sub-criterion show that AR is the criterion with the highest importance level (0.62). The AS criterion has the second highest weight value (0.310),and the AA criterion has the lowest (0.07).

A comparison of the importance levels of the sub-criteria of the COST criterion shows that the EC criteria, with a weight of 0.424, is the most important factor.

Consideration of the importance levels of the sub-criteria of the GF criterion shows that the LS criteria, with a weight of 0.490,aremore important than the DRL factor.

TOPSIS results

The TOPSIS application steps were solved using Excel formulations. The structure dealt with in the AHP hierarchy is adapted to this method of decision matrix. The importance levels of the main criteria and sub-criteria are the levels specified in the AHP.

The ideal and negative ideal solution of each alternative are determined using the values in Table 9; the distance from the ideal solution (S_i^*) and negative solution (S_i^-) are calculated; and the proximity of each alternative to the ideal solution (C_i^*) isdetermined. Alternatives are listed according to these priority values.

The best alternatives for site selection are listed in order of relative proximity to the ideal solution. The numerical value of each option similar to the ideal is calculated using the similarity index (S_i^*). According to TOPSIS results, the optimum location for consideration as the oil spill responsecenter in this region is the entrance to Izmit Bay, with a weight of 0.80, followed by Tekirdag which has the closest weight ratio of 0.43.Although

Table 5. Weights, pairwise comparison and consistency values of GEA sub-criteria

λ_{max}: 3.083 **RI:** 0.580 **CI:** 0.041 **CR:** 0.07				
	AR	**AS**	**AA**	**WEIGHT**
AR	1.000	0.121	0.165	**0.620**
AS	8.275	1.000	1.000	**0.310**
AA	6.046	1.000	1.000	**0.070**

Table 6. Weights, pairwise comparisons, and consistency values of COST's sub-criteria

λ_{max}: 3.01 **RI:** 0.580 **CI:** 0.01 **CR:** 0.007				
	CL	**LC**	**EC**	**WEIGHT**
CL	1.000	0.724	0.299	0.301
LC	1.382	1.000	0.496	0.275
EC	3.349	2.015	1.000	0.424

Table 7. Weights, pairwise comparisons, and consistency values of GF's sub-criteria.

	DRL	**LS**	**WEIGHT**
DRL	1.000	1.015	0.510
LS	0.985	1.000	0.490

Table 8. Ideal and negative ideal solution values

	PSA	PRA	POT	PIST	PCC	PS	AR	AS	AA	CL	LC	EC	DRL	LS
Ideal solution values	0.07	0.01	0.02	0.03	0.02	0.01	0.26	0.06	0.03	0.01	0.01	0.03	0.24	0.47
Negative ideal solution values	0.12	0.27	0.18	0.13	0.10	0.03	0.43	0.26	0.06	0.30	0.23	0.40	0.31	0.07

Table 9. Results of the site selection priorities

	S_i^*	S_i^-	C_i^*
TEKIRDAG REGION	0.5151	0.4005	0.4374
ISTANBUL STRAIT ENTRANCE	0.6601	0.3083	0.3184
IZMIT BAY ENTRANCE	0.1692	0.6837	0.8016

Entrance of Istanbul Strait is the region with the most intensive ship traffic, it is the third most suitable site for oil spill response location.

Conclusion and discussion

In this study, it has beenconcluded that deployment period and mobilization time on spill site are the key determinants in the effectiveness of the operation.Proximity to risky areas determines the efficiency of the response operation depending on the reaction time.In addition, easy accessto response centeris extremely important, especially in terms of the transfer of heavy equipment and waste transportation. Furthermore, the cost, which is often the most important variable in the construction of anew facility, loses its importance if the new facility will be used as an oil spill response center. In other words, as response operations are an activity carried out in the public interest, it is emphasized that the facility to serve this operation should have the most extensive infrastructure.

This study showed that land properties are the least important criteria, which indicates that even prefabricated structures may be sufficient because the area is actually focused on maritime activities and the facility to be installed must have compact features that can be easily transported when needed. Therefore, there is not a high need for high-rise structures in terms of minimizing the risks of creating the most important natural disaster in the region.

Based onthe results,it is concluded that the most suitable location for the oil spill response center in the region is Izmit Bay Entrance. This location has been proposed for the response to headquarters to manage the whole operation with the assistance of auxiliary installations in the area. Therefore, other recommended areas can be considered as auxiliary stations or as equipment storage areas. Of course, the location of auxiliary stations and equipment storage areas can be considered as a matter of future work.

In the light of the risk maps generated in the past studies on the oil spill in this region, it is seen that the determined optimum location in this study is found as the place closest to the risky areas. In addition, spill simulations show that the most risky areas in the region are the entrances of Istanbul Strait and Izmit Bay. Besides, oil spills always threat southern region in the Marmara Sea under the influence of dominant current pattern. Thus, oil spill response strategies have to be developed under main environmental factors.

In this study, the AHP and TOPSIS methods, which are the most preferred MCDM techniques, have been used to determine the optimum location for the oil spill response center. In the future, it is recommended to use other numerical methodsfor better solutions. In this study, only technical and operational variables have been taken into account, but political and administrative criteria have been excluded.Therefore, it is recommended to consider these variables in future studies.

There are limited studies on the optimum site selection of the oil spill response centers in the literature. One of the most important contributions of this study to the related science is that itwas carried out in the Marmara Sea, one of the most intensive ship traffic areas of the world;it is very important both in terms of literature contribution and effectiveness of emergency response operation.

Acknowledgements

The authors would like to thank MEKE Oil Spill Response Company and Seagull Oil Spill Response Limited for their help in providing data and DokuzEylul University Maritime Faculty for their support in this study. The comments and suggestions of two anonymous referees and the area editor helped improve the paper significantly.

References

Aktar, M., Çemen, İ. & Yılmaz, Y. (2017). Fault structures in Marmara sea (Turkey) and their connection to earthquake generation processes, *Active Global Seismology: Neotectonics and Earthquake Potential of the Eastern Mediterranean Region*, pp. 225.

Akten, N. (2004). Analysis of shipping casualties in the Bosphorus, *The Journal of Navigation,* 57, 3, pp. 345–356.

Alpar, B. & Unlu, S. (2007). Petroleum residue following Volgoneft-248 oil spill at the coasts of the suburb of Florya, Marmara Sea (Turkey): A Critique, *Journal of Coastal R.*, 23, 2, pp. 515–521.

Başar, E. (2010). Weathering and oil spill simulations in the aftermath of tanker accidents at the junction points in the Marmara Sea, *Fresenius Environmental Bulletin*, 19, 2, pp. 260–265.

Basar, E., Kose, E. & Guneroglu, A. (2006). Finding risky areas for oil spillage after tanker accidents at Istanbul strait, *International Journal of Environment and Pollution*, 27, 4, pp. 388–400.

Belardo, S., Harrald, J., Wallace, W.A. & Ward, J. (1984). A partial covering approach to siting response resources for major maritime oil spills, *Management Science*, 30, 10, pp. 1184–1196.

Beskese, A., Demir, H.H., Ozcan, H.K. & Okten, H.E. (2015). Landfill site selection using fuzzy AHP and fuzzy TOPSIS: A case study for Istanbul, *Environmental Earth Sciences*, 73, 7, pp. 3513–3521.

Birpınar, M.E., Talu, G.F. & Gönençgil, B. (2009). Environmental effects of maritime traffic on the İstanbul Strait, *Environmental Monitoring Assessment*, 152, pp. 13–23.

Bolat, F. (2011). An analysis of Marmara region ports potentials as of main hub port features (Doctoral dissertation). Istanbul Technical University, Istanbul, Turkey. (in Turkish)

BOSMAR (2017). Tanker Terminals at Marmara Sea, (http://bosmaragency.com/marmara-sea/(05.02.2018)).

Bozkurtoglu, S.N.E. (2017). Modeling oil spill trajectory in Bosphorus for contingency planning, *Marine Pollution Bulletin*, 123, pp. 57–72.

Çelik, M. & Topcu, Y.İ. (2009). Use of an ANP to prioritize managerial responsibilities of maritime stakeholders in environmental incidents: An oil spill case, *Transportation Research Part D*, 14, pp. 502–506.

Charnes, A., Cooper, W.W., Karwan, K.R. & Wallace, W.A. (1979). A chance-constrained goal programming model to evaluate response resources for marine pollution disasters, *Journal of Environmental Economics and Management*, 6, 3, pp. 244–274.

Chen, S.J. & Hwang, C.L. (1992). Fuzzy multiple attribute decision making methods, In: *Fuzzy multiple attribute decision making* (pp. 289–486). Springer, Berlin, Heidelberg.

Church, R. & ReVelle, C. (1974). The maximal covering location problem. In: *Papers of the Regional Science Association*. Springer, Verlag.

Coskun, S.S. (2016). Selection of residential construction site using geographic information system based AHP rating model, *Journal Eurasian Academy of Sciences Eurasian Business & Economics*, 2, pp. 530–540.

Dagdeviren, M. (2002). Developing a new analytical job evaluation technique using analytical hierarchy process (Master Thesis). Gazi University, Ankara, Turkey. (in Turkish)

Dagdeviren, M., Eraslan, E., Kurt, M., & Dizdar, E.N. (2005). An alternative approach to a supplier selection problem analytical network process, *Teknoloji*, 8, 2, pp. 115–122. (in Turkish)

Dogan, E. & Burak S. (2007). Ship-originated pollution in the Istanbul Strait (Bosphorus) and Marmara Sea, *Journal of Coastal Research*, 23, 2, pp. 388–394.

Ertugrul, I. & Karakasoglu, N. (2008). Comparison of fuzzy AHP and fuzzy TOPSIS methods for facility location selection, *The International Journal of Advanced Manufacturing Technology*, 39, 7–8, pp. 783–795.

Essiz, B. & Dagkiran, B. (2017). Accidental risk analyses of the Istanbul and Canakkale straits, In: *IOP Conference Series: Earth and Environmental Science*, IOP Publishing.

Gumusay, M.U., Koseoglu, G. & Bakirman, T. (2016). An assessment of site suitability for marina construction in Istanbul, Turkey, using GIS and AHP multicriteria decision analysis, *Environmental Monitoring and Assessment*, 188, 12, pp. 677.

Guven, C.K., Çubukçu, N., İpteç, M., Ozyalvaç, M., Cumali, S., Nesimigil, F. & Yalçın, A. (2007). Oil and detergent pollution in surface waters and sediments of the Istanbul Strait, Golden Horn, Izmit Bay (Sea of Marmara), Çanakkale Strait, Aliağa (Aegean Sea) in 2005–2007, *Journal of Black Sea/Mediterranean Environment,* 14, pp. 205–220.

Guven, K.C., Yazici, Z., Ünlü, S., Okus, E. & Dogan, E. (1996). Oil pollution on sea water and sediments of Istanbul Strait, caused by Nassia tanker acciden, *Journal of Black Sea/Mediterranean Environment*, 2, 1.

Ha, M.J. (2018). Modeling for the allocation of oil spill recovery capacity considering environmental and economic factors, *Marine Pollution Bulletin*, 126, pp. 184–190.

Hanine, M., Boutkhoum, O., El Maknissi, A., Tikniouine, A. & Agouti, T. (2016). Decision making under uncertainty using PEES–fuzzy AHP–fuzzy TOPSIS methodology for landfill location selection, *Environment Systems and Decisions*, 36, 4, pp. 351–367.

Hanine, M., Boutkhoum, O., Tikniouine, A. & Agouti, T. (2017). An application of OLAP/GIS-Fuzzy AHP-TOPSIS methodology for decision making: Location selection for landfill of industrial wastes as a case study, *KSCE Journal of Civil Engineering*, 21, 6, pp. 2074–2084.

Hong, L. & Xiaohua, Z. (2011). Study on location selection of multi--objective emergency logistics center based on AHP, *Procedia Engineering*, 15, pp. 2128–2132.

Hwang, C.L. & Yoon, K. (1981). *Multiple attribute decision making: methods and applications: a state-of-the-art survey*, Springer--Verlag, New York.

Iakovou, E., Ip, C.M., Douligeris, C. & Korde, A. (1997). Optimal location and capacity of emergency cleanup equipment for oil spill response, *European Journal of Operational Research*, 96, 1, pp. 72–80.

IHS (2017). The module of Maritime Intelligence Risk Suite: Marmara Sea Region Traffic density and risk visualization. U.K.

ITOPF (International Tanker Owners Pollution Federation Limited). (2002). Contingency Planning for Marine Spills, Technical information paper. (http://www.itopf.com/fileadmin/data/Documents/TIPS%20TAPS/TIP16 Contingency Planning for Marine Oil Spills.pdf./(29.12.2017)).

Kharat, M.G., Kamble, S.J., Raut, R.D., Kamble, SS. & Dhume, S.M. (2016). Modeling landfill site selection using an integrated fuzzy MCDM approach, *Modeling Earth Systems and Environment*, 2, 2, pp. 53.

Nordvik, A.B. (1999). Time window-of-opportunity strategies for oil spill planning and response, *Pure and Applied Chemistry*, 71, 1, pp. 5–16.

O'Brien, M.L., Jones, R. & Moore, D.M. (2017). Preparedness decision making in offshore oil and gas-how much is enough? In: *International Oil Spill Conference Proceedings*. Longbeach, California.

Olson, D.L. (2004). Comparison of weights in TOPSIS models, *Mathematical and Computer Modeling*, 40, 7–8, pp. 721–727.

Ors, H. (2003). Oil transport in the Turkish Straits system: A simulation of contamination in the Istanbul Strait, *Energy Sources*, 25, 11, pp. 1043–1052.

Otay, E.N. & Yenigun, O. (2000). Volgoneft-248 oil spill in the Marmara Sea, In: *Proceedings of 2nd International Conference on Oil Spills in the Mediterranean and Black Sea Regions*.

Psaraftis, H.N., Tharakan, G.G. & Ceder, A. (1986). Optimal response to oil spills: the strategic decision case, *Operations Research*, 34, 2, pp. 203–217.

Saaty, T.L. & Vargas, L.G. (1982). *The logic of priorities: applications in business, energy, health, and transportation*, Kluwer-Nijhoff, The Hague.

Saaty, T.L. (1980). *The analytic hierarchy process: planning, priority setting, resources allocation*, McGraw, New York.

Soltanalizadeh, A., Ramezanzadeh, A. & Jalali, M.E. (2014). Determining appropriate natural caves for underground crude oil storage by admixture FAHP and TOPSIS methods, *Journal of Engineering Geology*, 8, 3, pp. 2239–2260.

Srinivasa, A.V. & Wilhelm, W.E. (1997). A procedure for optimizing tactical response in oil spill clean-up operations, *European Journal of Operational Research*, 102, 3, pp. 554–574.

Timor, M. (2011). *Analytic hierarchy process*, Türkmen Kitabevi, Istanbul. (in Turkish)

TMRCC (Turkish Maritime Rescue Coordination Center), (2017). Ship accident statistical data of Marmara Sea. Technical information paper, Turkey.

Toz, A., Koseoglu, B. & Sakar, C. (2016). Numerical modelling of oil spill in New York Bay, *Archives of Environmental Protection*, 42, 4, pp. 22–31.

Tugrul, S., Besiktepe, T. & Salihoglu, I. (2002). Nutrient exchange fluxes between the Aegean and Black Seas through the Marmara Sea, *Mediterranean Marine Science*, 3, 1, pp. 33–42.

Unlu, S. (2007). Comparative analytical data in the source determination of unknown spilled oil in the Haydarpasa Port (Marmara Sea), Turkey, *Bulletin of Environmental Contamination Toxicology*,78, pp. 363–367.

Usluer, H.B. & Alkan, B.G. (2016). Importance of the marine science and charting about environmental planning, management and policies at the Turkish straits, *European Journal of Sustainable Development Research*, 1, 1, pp. 16–25.

Verma, M., Gendreau, M. & Laporte, G. (2013). Optimal location and capability of oil-spill response facilities for the south coast of Newfoundland, *Omega*, 41, 5, pp. 856–867.

Wang, H., Xu, J., Zhao, W.& Zhang, J. (2014). Effects and risk evaluation of oil spillage in the sea areas of Changxing Island, *International Journal of Environmental Research and Public Health*, 11, 8, pp. 8491–8507.

WWF (World Wildlife Found), (2007). Oil spill response challenge in Arctic Region. Technical Report. Nuka Research and Planning Group, LLC, October 2007.

Yap, J.Y., Ho, C.C. & Ting, C.Y. (2017). Analytic Hierarchy Process (AHP) for business site selection. *The 6th International Conference on Computer Science and Computational Mathematics*, Kuala Lumpur, Malaysia.

Yari, M., Monjezi, M. & Bagherpour, R. (2013). Selecting the most suitable blasting pattern using AHP-TOPSIS method: Sungun copper mine, *Journal of Mining Science*, 49, 6, pp. 967–975.